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Primitive Palms: A density study on the impacts of harvesting natural materials for construction purposes on Sumak Allpa of the Amazon rainforest

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SIT Study Abroad

PRIMITIVE PALMS

A density study on the impacts of harvesting natural materials for construction purposes on Sumak Allpa of the Amazon rainforest

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ABSTRACT

In an effort to better understand how rural construction techniques affect a surrounding environment, this study combines a density test of the natural building materials used in the construction of a school on Sumak Allpa island of the Orellana Province in the Amazon basin of Ecuador. The focus of the study measures the density of the bamboo species *Guadua angustifolia* and the Panama hat plant *Carludovica palmata* on the island while noting a comprehensive compilation of the techniques and materials used in the building process. Using a mix of plots and transects, a comparison of harvested material to remaining material left in each habitat was conducted. Under further analysis, the harvested individuals of the studied species had little to no effect on the overall health of the island's populations. Similarly, through both qualitative and quantitative data collection, the environmental impact of reconstructing the school—using various primitive techniques—did not have a significant negative effect on the ecosystem. After 26 days of observation and participation, it can be further concluded that the relationship between man and nature is strengthened by understanding the laborious and intentional process by which a shelter is created.

RESUMEN

En un esfuerzo por comprender mejor cómo las técnicas de construcción rural afectan el medio ambiente circundante, este estudio combina una prueba de densidad de los materiales de construcción naturales utilizados en la construcción de una escuela en la isla Sumak Allpa de la Provincia de Orellana en la Amazonia de Ecuador. El enfoque del estudio mide la densidad de la especie de bambú *Guadua angustifolia* y la planta de sombrero de Panamá *Carludovica palmata* en la isla, al tiempo que se observa una compilación exhaustiva de las técnicas y los materiales utilizados en el proceso de construcción. Usando una mezcla de parcelas y transectos, se realizó una comparación del material recolectado con el material restante que queda en cada hábitat. Bajo un análisis adicional, los individuos recolectados de las especies estudiadas tuvieron poco o ningún efecto sobre la salud general de las poblaciones de la isla. De manera similar, a través de la recopilación de datos tanto cualitativos como cuantitativos, el impacto ambiental de la reconstrucción de la escuela, utilizando diversas técnicas primitivas, no tuvo un efecto negativo significativo en el ecosistema. Luego de 26 días de observación y participación, se puede concluir que la relación entre el hombre y la naturaleza se fortalece al comprender el proceso laborioso e intencional mediante el cual se crea un refugio.

ACKNOWLEDGEMENTS

May I first give my utmost gratitude to those who made this study possible. Xavier Silva, Ph.D. and Javier Robayo, thank you for enriching my love of the natural world and for opening up my eyes to the ways in which we can change our lives to better suit the world around us. This project could not be a better fit for an architectural engineering student like myself; thank you for meshing two of my passions—nature and construction—into the most altering experience of my life. I would also like to thank my academic advisor, Héctor Vargas, for this opportunity to not only participate in this research project on Sumak Allpa, but for trusting me to help construct the school piece by piece. The island is a home away from home for me; the hospitality, the generosity, and the simplicity of life I will hold close to my heart and cherish every day ahead. I wish you the best as tourists and students now have a revamped space to learn and gather about conservation. Thank you to Luís and Román, the architects and muscles of the project; you have taught me more than just craftsmanship and workmanship. Watching 2 sets of hands tie palm leaves onto the roof for 10 hours a day has forever instilled in me an appreciation for all types of natural construction—I will never look at a thatched roof in the same way again! I am still astounded how an entire house could be built by the blade of a machete. Thank you for your patience with me, for your laughter, and for seeing me as a part of the team. Thank you to my island co-habitants: Annamarie Ranallo, Brynn Furey, and Emma Kelley, all of whom kept me stable mentally and emotionally, as well as well-fed after such long days of work. Thank you for volunteering your time in the building process and for showing me through the treacherous jungle trails. And finally, bless all those in between and behind the scenes: Wendy Aranda, Tamia Aranda, Juan Vargas, Mama Mia, Ana Maria Ortega Alvarez, and Diana Serrano.

INTRODUCTION

In the heart of South America lies 6,000,000 square kilometers of the dense Amazon basin (Amazonia) that spreads across Brazil, Columbia, Bolivia, Peru, and finally hindered by the great Andean foothills of Ecuador ("Amazon Rainforest",2019). The species richness and biodiversity of the area remains as the greatest in the world, with a multitude of abiotic features that keeps this river basin beyond unique. With lush nutrient rich soils, vegetation thrives as it has grown well suited for high temperature and heavy flooding of Amazonia. Palms, Cecropia trees, and bamboo all intermix their roots under the layers of decomposing flora—only a leaflet of the fauna that prosper in the spread of tierra firme, várzea, and igapó ecosystems within this region ("Amazon River", 2019).

Unfortunately, as the global demand rises for lumber, produce, and livestock, Amazonia has been one of the main sources for invasion and export. Ecuador is at the forefront of this battle: due to breaking boundaries of protected areas throughout Amazonia, threating activities have sparked much conflict between the government and Ecuador's people—mining projects, illegal logging, palm plantations, and transportation projects (Bass, et al., 2010). For example, the most biodiverse protected areas in the world, Yasuní National Park, sits above a large amount of natural oil reserves. But as of 2013, the oil ban was lifted, and extraction project began early in 2016 ("Amazon Rainforest",2019). Yasuní National Park continues to remain protected on other fronts—but will cracking open the door for a single resource open the doors to more extraction of other natural resources?

The threating behavior of the government has raised questions and urgency towards fighting for change. Even when it comes to extracting oil, forests need to be cleared and burned, adding to the rate of deforestation insurmountably (Bass, et al., 2010). As a drilling site is finally claimed, road crews arrive bringing loggers, farmers, and miners close behind; studies show that a single road can trigger a wave of negative environmental changes throughout the remaining forest (Fraser, 2014). In a study over the first decade of the 21st century discussing forest fragmentation in the Amazon basin of Brazil, it was found that nearly 38,000 km of new forest edge is created each year (Cochrane, 2008). And although most construction sites average 7km from the nearest road in Amazonia, it is paving the way for newcomers to settle, slash, and burn for their own benefit (Fraser 2014). Therein lies exponential destruction of Amazonian ecosystems and habitats for both micro and macrofauna; however, there are active efforts that continue to promote education, awareness, and protection of the most biodiverse area in the world.

Figure 1: The country of Ecuador with a focus on the Orellana Province wherein Sumak Allpa lies

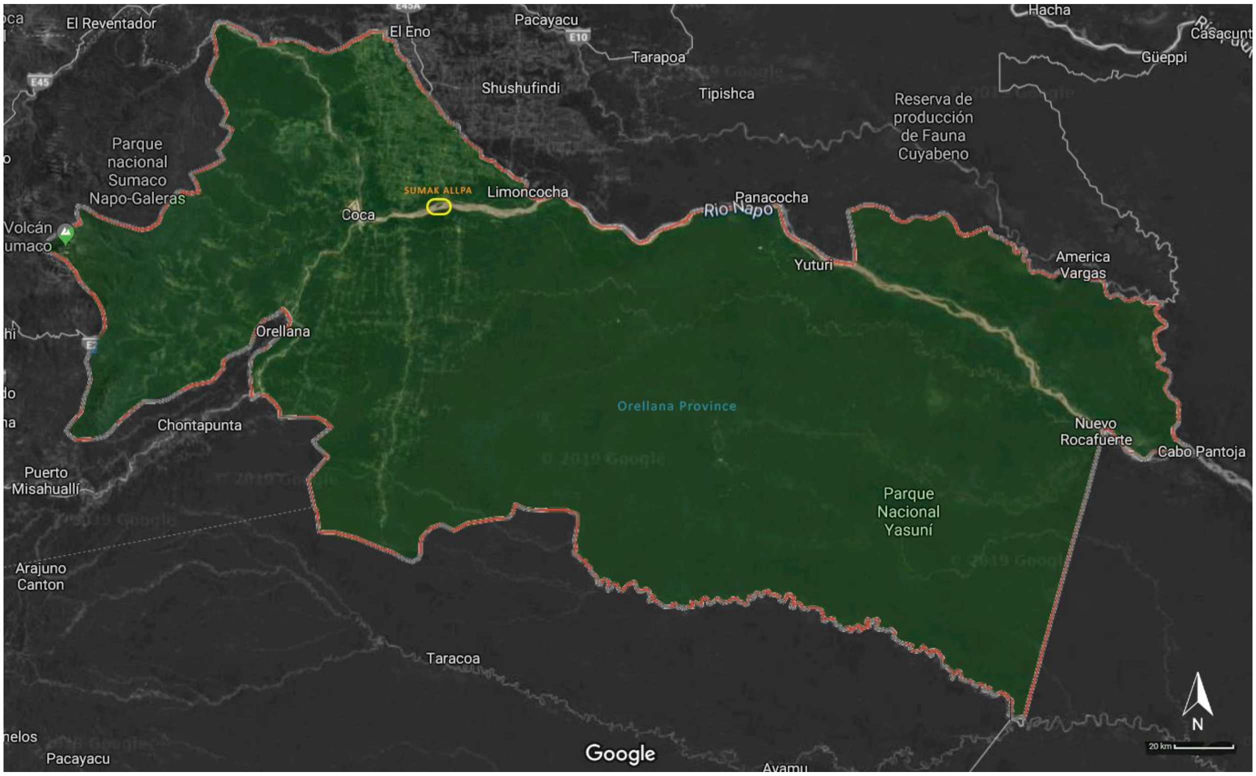


Figure 2: Orellana Province encompasses Yasuní National Park, and Sumak Allpa, found due east of Coca on the Napo river

Sumak Allpa

In 2000, a project called Sumak Allpa was established amidst the Amazon in the Orellana Province, Ecuador. With 115 hectares of land resting in the middle of the Napo River, promoting the protection of wildlife, culture, and the ecosystems of the Amazon on this island reserve (Vargas, 2012). The lead director, Héctor Vargas, for the last 19 years, has built up the island to what it is today: working alongside indigenous tribes, teaching the public about reforestation, and creating an atmosphere that is centered around environmental awareness. Héctor has worked as an Amazon rainforest guide for more than 30 years, bringing groups into the Amazon to educate them about the oil industry, wildlife, and common practices within Amazonian tribal communities (Vargas, 2012). Sumak Allpa is known for the restoration and conservation of Amazonian monkey species from the canopy to the understory. With over six different species of monkey—including Woolly Monkeys (*Lagothrix lagotricha*) and Saki Monkeys (*Pithecia aequatorialis*)—and more than 100 individuals rescued as of 2019, the island works to bring these monkeys out of global endangerment and eventually relocation to non-threatened habitats.

The island was transformed from a cacao and coffee plantation into a super-sized rehabilitation habitat as a wide variety of palms, bamboos, and hard woods were introduced (Freimuth, 2018). With the intention of limiting the number of imports to the island, natural construction materials such as the "Conambo" palm and the species *Guadua angustifolia* (bamboo) have allowed for the construction of six different lodging facilities and several other amenities to remain local and eco-friendly.

Low-impact natural construction materials

One of the key practices and necessities of any community is building shelter. Without the resources or access for large scale construction projects, the majority of these communities have adopted bamboo building techniques.

Worldwide, of the 1200 different species of bamboo, approximately 20 are suitable for construction use (Escamilla, 2014). And bamboo is a super-plant when it comes to construction: ounce for ounce, bamboo is stronger than wood, concrete, and brick (Roach, 1996). It is both high strength and light weight, giving it a great mechanical advantage over common wood materials (Xinping, 2018). In a compression test, the species of bamboo *Dendrocalamus Asper* withstood loads up to 232.31 N/mm^2 compared to spruce that had a tensile strength of 89 N/mm^2 (Awalluddin, 2017). The high strength properties come from the makeup of the plant, which is a combination of cellulose fibers and lignin filler material. It has an elastic modulus that is close to steel—due to the lignin that keeps it from crumbling—while on the other hand the cellulose keeps it from buckling under excessive pressure (Roach, 1996). Therefore, bamboo constructed homes can withstand seismic wave activity well. In 1991, soon after twenty bamboo homes were built in a town in Costa Rica, a 7.5 magnitude earthquake stuck the area, yet all twenty homes remained intact (Roach, 1996). From an environmental and economic standpoint, bamboo is low-cost and has a low carbon footprint (Escamilla, 2014). This is what makes bamboo construction so abundant in areas of the jungle. Little to no large-scale equipment is needed when assembling a bamboo structure, only certain knowledge about assembly techniques is required (Xinping, 2018).

Another low-impact natural resource for housing development have been palm leaves. Over the course of history, roof thatching using palm leaves and stalks has been a low-cost solution to those in rural areas (Umar 2017). There are several species of palms—like *Geonoma deversa*—that has been grown widespread across the Amazonian Basin (Flores, 2000). In a study when measuring the harvesting impacts of these compared to another palm species *Geonoma congesta*, the cutting of an entire crown caused negative damage, whereas for the species *G. congesta* it increased the rate of leaf production. (Flores, 2000). Speaking specifically on palm construction, the amount of product that actually reaches the market is often lower because of poor transport infrastructure and market inefficiency as well (Godoy, 1993).

The *Iriartea* genus has grown quite popular for construction purposes within Ecuador especially. Standing at 20-35m tall, the leaves reach up to 5m long and pinnate. When split and dried, the leaves act as impermeable roofing material attached to one another with vine or rope (Fadiman, 2019). Its uses go beyond roof thatching, all parts of the palm are said to be used: palm wood, leaves, roots, and fruits. In Ecuadorian housing construction, the species *I. deltoidea* palm wood is known as "pambil" of which is both flexible and durable, best used for rounded walls or heavy-loaded structural. It has brought economical and even environmental awareness to construction within small communities, who claim to work around the natural life cycle of the palm points (Fadiman,2019).

And throughout the dense primary forest of Sumak Allpa, species such *I.detoidea* have been used to construct the facilities of the island. At the start of this study the lead director, Héctor Vargas, invited me into the helping with the building process of reconstructing their current thatched roof school. It was last reconstructed ten years ago, and all things considered the structural integrity of the school was on its last leg. Most of the materials would come directly from the island. Within the scope of this study, construction techniques that involved *Iriartea deltoidea*, *Calycophylum spruceanum*, and *Attalea butyracea* are significant; however, the focus of the study was centered on the densities of the bamboo species *Guadua angustifolia* and Panama hat plant (*Carludovica palmata*) on Sumak Allpa.

Density Study

In order to analyze the eco-impacts of constructing a bamboo and palm facility on the island, a count of the number of individuals must be investigated. In studies such as the environmental impact of building with bamboo—composed by Escamilla and Habert—they analyzed 1m^3 bamboo shoots and the output of emissions and energy needed for each succeeding step in construction (Escamilla, 2014). Density tests have also seen great success, for they offer insight about a particular population of one area. Looking at studies conducted by Flores and Ashton—who were measuring the environmental impacts of harvesting *Geonoma deversa,* a roof palm—measured the density of palms within a 0.25 ha specified area. Then following the harvest of these plots, they used Tukey's Studentized T-Test, labor hours needed for harvest, and the number of surviving palms after harvest, they concluded the effectiveness of such practices (Flores, 2000). This type of application is common among density studies and can help quantify the environmental impacts of harvesting natural materials for construction purposes.

The increase in construction use of bamboo have also prompted several studies on the global densities; as a grass, bamboo grows in culms and can often self-thin their populations. In Japan of 2018, an investigation was conducted to find the maximum size-density relationship (MSDR) of the widely spread and highly demanded bamboo species, *Phyllostachys pubescens* (Inoue, 2018). The MSDR was calculated by recording the DBH at various sites across over 800 hectares and using a logarithmic function to relay more information about the grass' density. With intentions to better control the growth to consumption ratio, including invasiveness to other neighboring species, it was discovered that with an MSDR of -2 would keep the carrying capacity at a manageable degree (Inoue, 2018). This mathematical technique is best for large scale density studies, where over-growth or self-deprivation is present.

Consequently, the majority of density studies that I have found were conducted over large scales; looking closer at the environmental impacts on a smaller scale—one community's sourcing for construction—could hold just as much environmental significance. Sumak Allpa became that place: isolated, limited population, introduced species for construction. A density study of várzea ecosystem, one that is inundated for the majority of the year, on bamboo and the Panama hat palm has could yield interesting plant behaviors on Sumak Allpa.

While investigating the population densities of *G.angustifolia* and *C.palmata,* the goal of this study is to understand how the reconstruction of the school affects the overall ecosystem on Sumak Allpa. In doing so, conclusions may be made about the interactions between locally harvested plants and its community. This is the first investigation conducted on the island; may it serve as a baseline for other environmental density studies in the future. Hopefully, this can promote actions to limit the export of timber—which could vastly decrease the rate of deforestation—and educate others to build a future around constructing with local and naturally-grown materials.

METHODS AND MATERIALS

Density Study Materials

- 60m Measuring Tape
- String
- Palm Shoots (used for marking clusters of palms)
- Camera (GoPro HERO 7 Black)

Study Site

The island of Sumak Allpa rests 20km east of Coca (0°26′24″ S 76°49′02″ W) in the Orellana Province of Ecuador. Even at 315m above sea level, the heavy flooding from the Napo River due to the inundated periods of a Várzea ecosystem can consume the island with over 3200mm of rainfall each year (Freimuth, 2018). The annual temperature ranges from 24°C to 27°C, while the humidity fluctuates between 80% -94%. This study was conducted during the wet season from April 13th to May 7th, 2019.

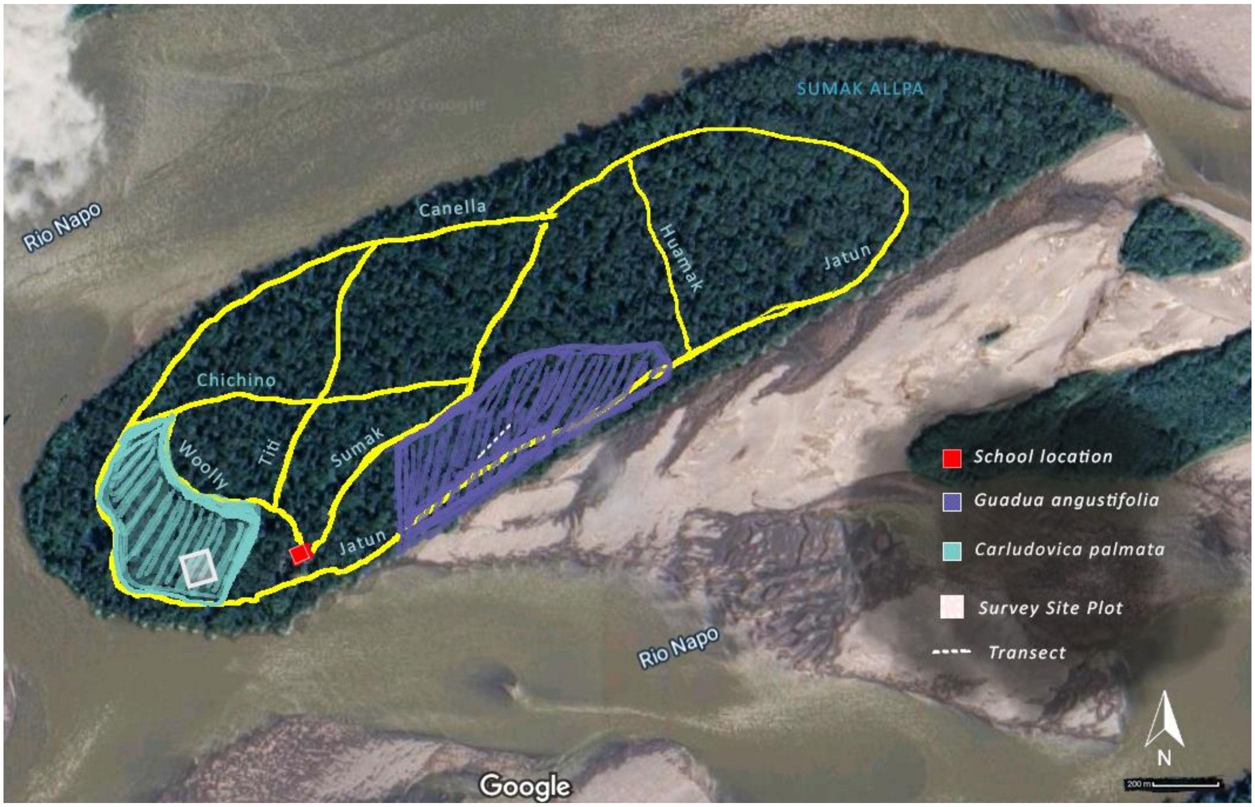


Figure 3: Sumak Allpa Island The seven trails of Sumak Allpa, location of school, and estimated sections for the Panama hat plant--Carludovica palmata--and bamboo--*Guadua angustifolia*--both for reconstruction purposes. The Panama hat plant survey site was located on the southwestern end of the island; the bamboo survey transect was located northeast of the school.

With the turn of the 21st century came the transformation of the island's soils: cacao and coffee plantations were dug up and replaced with endemic plant species. Twenty years later, 80% of the island is considered primary forest, 20% secondary forest. With hundreds of hectares of canopy coverage, the needs of the rescued monkey species are abundant and growing.

The surveyed sites are highlighted in Figure 3. The leaves of the Panama hat plant—*Carludovica palmata*—dominate the southwestern tip of Sumak Allpa. The plots were chosen after being guided by Luis Aranda to the most common location for harvesting Panama hat plants on the island. Rigid and water resistant in numbers, this species has been used in low-cost roof thatching for decades across the Amazon basin. The bamboo species, *Guadua angustifolia,* was also chosen with the help of Luís where the most accessible and approximate peak density lied. On the island, all of the six infrastructures benefit from the ample number of palms and bamboo on the island, all of which use bamboo in construction, three of which use the Panama hat plant. For this study, the environmental impacts and density was strictly measured only for the reconstruction of the school (Figure 3).

As stated, two plots were created in order to measure the density of both the Panama hat plants and bamboo of the island. Starting from an arbitrary point just east of Jatun trail, I trekked 50m due north with a bool of string in hand, rotated 90° and headed 50m east. I repeated this process until I had a 50m x 50m plot of which I divided into smaller subplots (Figure 4). For subplot 1, I started in the southwest corner of the plot and took a 90° turn every 10 meters until completing the square. This process was repeated starting from the northwest corner of each succeeding subplot for 2-5. For subplot 5, I started in the northwest corner of the plot and took a 90° turn every

10m until completing the square as well. In the southeast corner of each succeeding subplot, I repeated this process for subplots 7-10 (Figure 4).

Although measuring the density of the Panama hat plant took priority, I conducted a further study that measured the environmental impacts of a constructing a school on the island. Within each subplot, the number of plants—one "plant" is categorized as any clusters of leaves within <0.5m of another—was recorded, as well as the total leaves per plant including those that were harvested; the number of harvested leaves per plant (only those with a the presence of transparent lubrication were counted); and the number of leaves, flowers, buds, or sprouts remaining, categorized as number of leaves left alive per plant. To mark each plant, the excess of Panama hat plant stems was placed horizontally after each said plant was recorded (Figure 5).

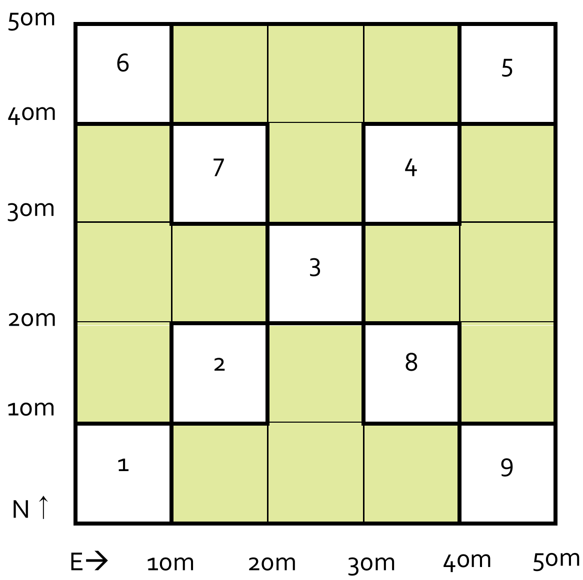


Figure 5 (right): Panama hat plant marking system: Pictured is how each plant was marked after counted

Figure 4 (left): Panama hat plant plot: A 50m x 50m plot broken into 10m x 10m subplots. The subplots that rested in both diagonals of the plot were labeled 1-9.

When conducting the density test for the bamboo—*Guadua angustifolia*—a transect with multiple quadrats were observed to be best fit for data collection. A 60m transect line was strung heading northeast 10m off of the Jatun trail to the east. From there three 5m x 5m quadrats were created using the measuring tape and string, set sporadically at 10m, 30m, and 60m down the transect (Figure 6). Quadrat 1 and 2 were chosen on the northwest side of the transect, whereas quadrat 3 was chosen on the southeast side. For each quadrat, the number of harvested shoots per quadrat (only those with the presence of fresh cut wounds were counted), and the number of shoots left alive were counted. Then, by summing these two groups, the total number of bamboo shoots was recorded per quadrat. It is worth noting that upon arrival 40 bamboo shoots had already been harvested for the school's roof.

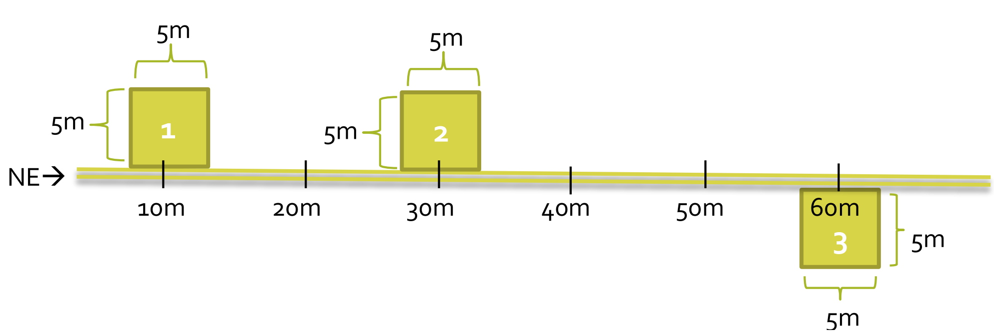


Figure 6: Diagram depicting transect created for bamboo density study. 5m x 5m quadrats were placed at 10m, 30m and 60m 10m off of Jatun trail heading northeast

The Construction Process

The building site rests at the southwestern edge of Sumak Allpa, near the entrance of Woolly Trail. The site measures 7m x 4.5m and is located at 0°26'37.0"S 76°49'13.2"W. With the guidance and assistance of the architects of the project, Luis and Román, along with the help from Héctor Vargas, Wendy Aranda, and Mama Mia, the entirety of the work was all completed by hand. All of the bamboo and wood was directly harvested from the island. Around 4000 Panama hat plant leaves were also harvested from the island; the remaining 4000 were harvested 5km east of Coca. Only 2 palm woods were harvested for the roofing structure, whereas 200 were delivered from elsewhere for the walls of the school. Therefore, boats were used for delivery of materials at times; regardless, the majority of the materials were sourced from the island and carried over by hand. Although a few other species of vines, trees, and palms were used during the construction of the school, they remain arbitrary in this study.

Within the first three days, the school was deconstructed, and all of the old materials were compiled and burned. The project then began with the construction of the roof: ceiling joists, top plates, rafters, and ridge beam, all of which were a combination of woods, palms, and bamboo (see Table 3 and Appendix A for further details). After each bamboo under purlin was installed, the panama hat plant stems were folded over itself to lock it in place. Over the course of 26 days, the roof was completed, and the floor was being leveled out with cement. Palm wood was also shaven down in preparation for the installation of new walls but were installed after the end of this study. All of the materials used for the completion of the school are listed below:

<u>Construction Materials</u>

- Machete & axe
- Hammer & nails (5cm, 4cm, 2cm)
- Rope, string and vines (*Araceae*)
- Ladder (3m & 8m)
- Old timber (used as scaffolding)
- Camera (GoPro HERO 7 Black)
- Bamboo- *Guadua angustifolia* (under purlins and rafters)
- Panama Hat Plant leaves-*Carludovica palmata* (roof thatching)
- Palm leaves- *Attalea butyracea* (water-wicking base)
- Hardwood-*Calycophylum spruceanum* (top plates, ceiling joists, ridge beam)
- Palm wood- *Iriartea deltoidea* (ridge beam, rounded ceiling joists, walls)

Figure 7: Completed thatched roof: Photographed May 6th, 2019 promptly after completing the final layer of the roof

RESULTS

The results include density data for the 50m x 50m plot Panama hat plant and the 60m transect for the bamboo used in the construction of the school. Lastly, data about the construction process and materials used conclude this section.

Panama hat plant density study

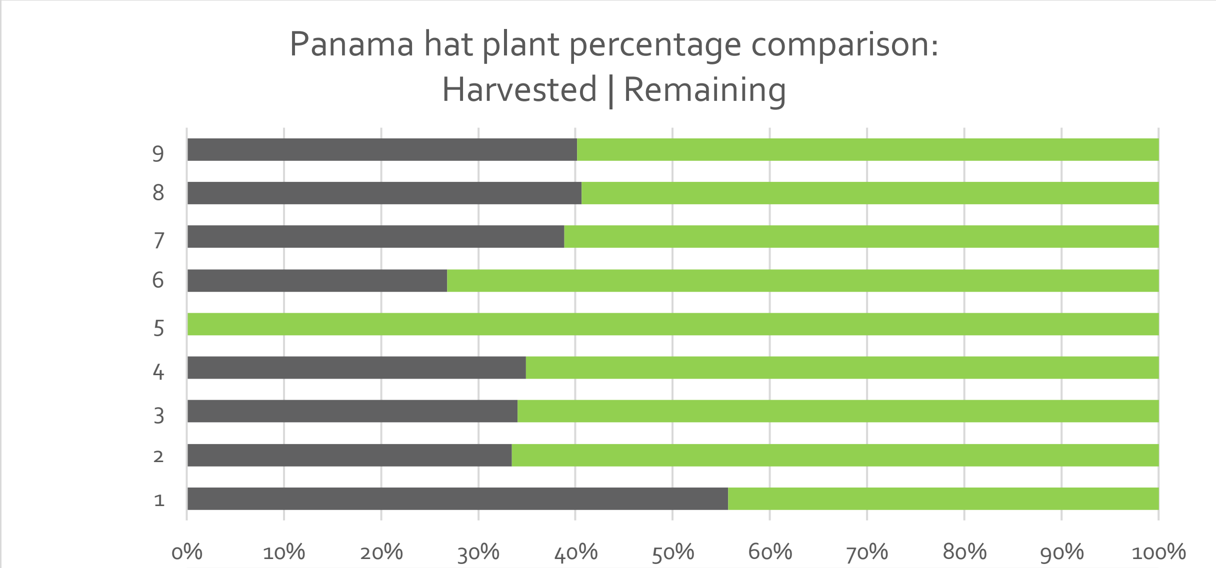
On Sumak Allpa, across the 9 different 10m x 10m subplots, 21,255 Panama hat plant leaves—*C.*palmata—were recorded over the course of the study; only ~8000 were needed to complete the construction of the school.

Subplot	Total	Average/plant
	Harvested	
1	1121	41
2	885	36
3	844	35
4	548	32
5	0	0
6	473	19
7	1238	45
8	1042	46
9	1261	47
	Remaining	
1	892	32
2	1758	38
3	1636	33
4	1023	28
5	1891	66
6	1293	32
7	1950	27
8	1522	21
9	1878	23
Total	**21,255**	

Table 1: (left) Panama hat plants--Harvested | Remaining Totals and averages, where *harvested* represents the number of leaves cut/plant and *remaining* includes any buds, sprouts, flowers, or leaves remaining/plant. Each sum refers to subplots 1-9 that are described in Methods section. The averages are based on the average number of leaves—harvested or remaining—per plant within each subplot.

Figure 8: (right) Panama hat plant leaves that have been harvested and separated for delivery; in the background complete plants are present.

Through the analysis of number of individual leaves cut ("Harvested") to the number of leaves left untouched ("Remaining"), it is noteworthy that no leaves were harvested from subplot 5 (Table 1). The average number of leaves harvested from each plant were slightly higher than the average number of leaves remaining per plant. Subplot 9 had the greatest number of harvested leaves, whereas subplot 7 had the greatest number of leaves remaining on the plants within its area.



	1	2	3	4	5	6	7	8	9
% Harvested	55.69	33.48	34.03	34.88	0.00	26.78	38.83	40.64	40.17
% Remaining	44.31	66.52	65.97	65.12	100.00	73.22	61.17	59.36	59.83

Figure 9: Panama hat plant percentage comparison Harvested | Remaining: Represents the percentage of leaves--harvested or remaining per plant for plots 1-9. It is significant that the majority of leaves per plant remained untouched. The data table beneath the graph gives numerical percentages for each subplot.

The comparison of the percentage of leaves harvested to the percentage of leaves remaining per subplot is demonstrated in Figure 9. With the exception of subplot 1, the percentage of leaves left untouched was greater than those that were removed for construction purposes across plots 2-9. Again subplot 5—in the northeastern-most corner of the 50m x 50m plot.

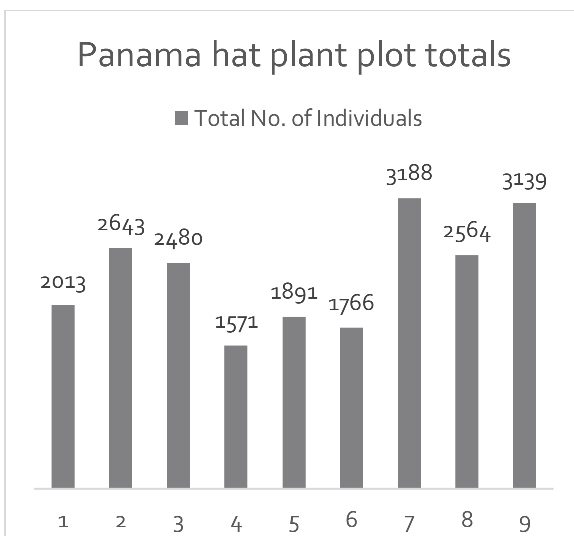


Figure 10: Panama hat plant subplot totals: Represents the number of individuals per plot 1-9. The greatest population was in plot 7.

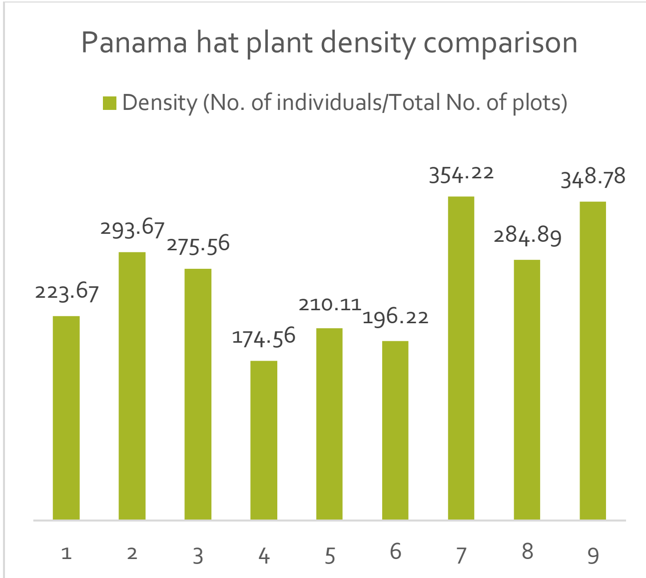
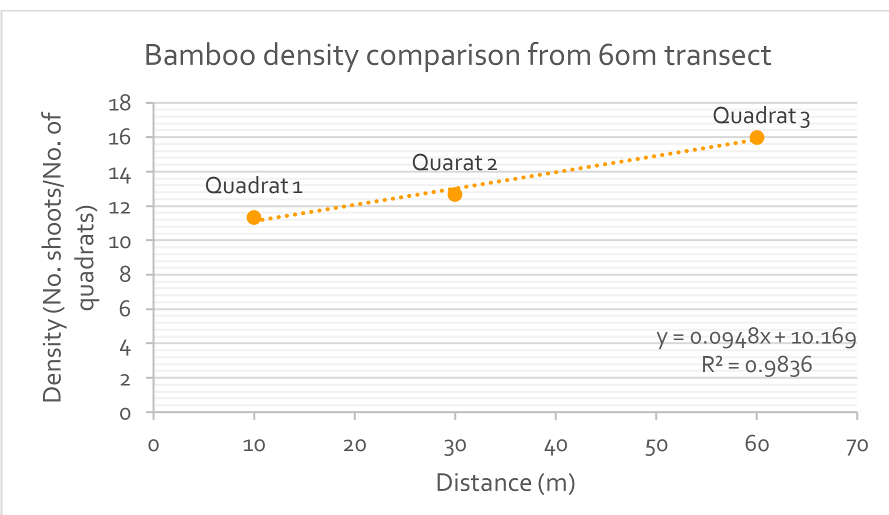


Figure 11: Panama hat plant density comparison: Density was calculated by taking the number of individuals divided by the total number of plots (9). Each plot was 100m². Similar shape seen in Figure 6.

The total number of individual Panama hat plant leaves per subplot show the summation of the number of leaves harvested and the number of leaves remaining. There was a 1617 leaf difference between the densest subplot (7) and the least dense (4) (Figure 10). The density of each subplot was the quotient of the number of individual leaves into the total number of subplots—9. The range is relative to the greatest value, where this particular dataset would range from 0 to 354.22 of subplot 7 (Figure 11). If the area of the plot was taken into consideration, about 4 leaves spread over every 1m².

Bamboo density study

On Sumak Allpa, a 60m transect was spread in the northeast direction 10m north of the Jatun trail. Three 5m x 5m quadrats were placed at 10m, 30m, and 60m where a bamboo—*G.angustifolia*—density study was conducted.



Quadrat	Harvested	Remaining
1	22	12
2	5	33
3	0	48

Figure 12: (left) Bamboo density comparison from 60m transect: Displays the bamboo density across quadrats 1-3 from the 60m transect. The average slope increases by 0.0948 as the R^2 value (goodness-of-fit) is 98.36%.

Table 2: (right) Quadrat totals: The total number of harvested and remaining bamboo shoots per quadrat. 27 shoots were recorded as harvested for the completion of the project.

Across the three quadrats, the number of harvested bamboo shoots and remaining shoots (including buds and currently-growing shoots—dead stumps were not recorded) were tracked. From quadrat 1 to 3, the number of harvested shoots decreased, inversely the number of remaining shoots increased (Table 2). The density of each quadrat was calculated by summing the number of shoots—harvested and remaining—and dividing by the total number of quadrats (3). Along the transect—based on the densities of quadrat 1-3: 11.33, 12.66, and 16—an increasing slope of 0.0948 was extrapolated (Figure 12).

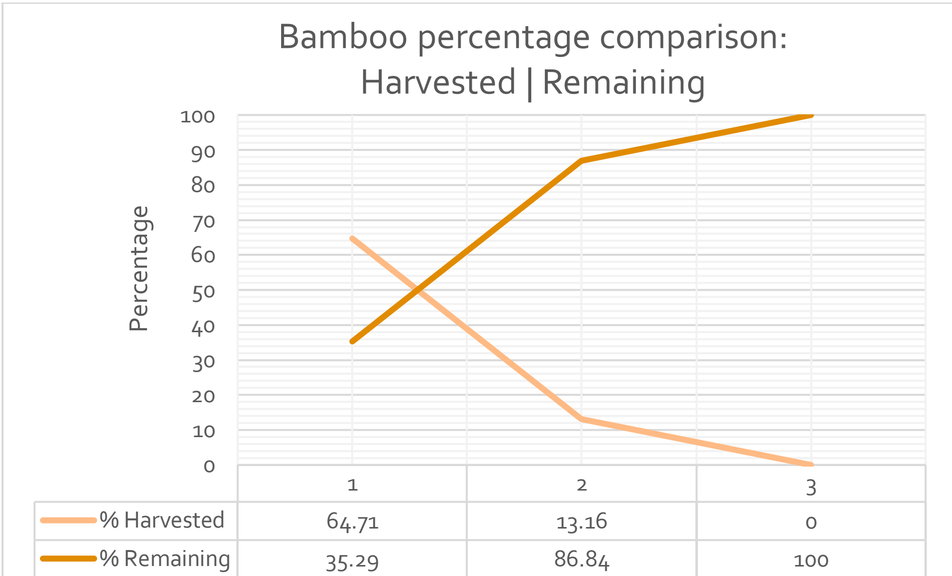


Figure 13: Bamboo percentage comparison: Harvested | Remaining: Along the 60m transect, a comparison of the number of bamboo shoots per quadrat 1-3. As the distance increases, the number of untouched bamboo shoots increases, whereas the percentage of harvested bamboo decreases.

A final comparison of the bamboo percentages between the harvested and remaining totals was created. The largest percentage of harvested bamboo shoots occurred within quadrat; there were no recorded harvested bamboo shoots in quadrat 3 (Figure 13). The percentages were calculated from the summation of the total number of individuals—harvested and remaining—per quadrat.

Construction process study
While conducting density research, I also took part in the reconstruction of the school on the island. This involved 10-hour days, working alongside Luis and Román. All of the materials used were 100% natural, without chemical treatments, obliviously with the exception of string and nails. The project was completed one day after the end of this study on May 8th, 2019.

Every day was recorded (Appendix B), and I created sketches and diagrams to further detail each step. The main five species that were used throughout the reconstruction were as follows:

- Bamboo- *Guadua angustifolia* (under purlins and rafters)
- Panama Hat Plant leaves-*Carludovica palmata* (roof thatching)
- Palm leaves- *Attalea butyracea* (water-wicking base)
- Hardwood-*Calycophylum spruceanum* (top plates, ceiling joists, ridge beam)
- Palm wood- *Iriartea deltoidea* (ridge beam, rounded ceiling joists, walls)

The rest of the materials can be found in the Methods and Materials section of this study. Every task includes any travel time as well for we usually worked from 7:30-5pm, resting when it rained.

Task	Purpose	Tools Used	Quantity	Hours of Labor
Hardwood- *Calycophylum spruceanum*-**(W)**				
Cutting (W)	Roof structure	Machete; axe	12	1
Shaving (W)	Prevents insect infestation	Machete; wooden mallet	12	6
Installing (W)	Ridge beam, ceiling joists, top plate	Vines; string; hammer; nails	12	8
Palm wood- *Iriartea deltoidea*- **(I)**				
Cutting (I)	Roof structure	Machete; axe	2	1
Splitting (I)	Thinner strips needed	Axe	8	X
Shaving (I)	Remove fibers	Machete	X	2
Installing (I)	Ceiling Joist	Vines; string	4	2
Installing (I)	Ridge beam	Vines; string	1	1
Shaving (I)	Wall replacements	Machete	140	22
Bamboo- *Guadua angustifolia*-**(B)**				
Cutting (B)	Roof structure	Machete; axe	40	X*
Installing (B)	Rafters	Machete	40	6
Cutting (B)	Roof structure	Machete; axe	6	1
Splitting (B)	Thinner strips needed	Wedge, axe, machete	72	2
Installing strips (B)	Under purlin	Hammer; nails; meter stick	60	3
Palm- *Attalea butyracea*- **(A)**				
Cutting (A)	Harvested for shingling	Machete	4	1
Splitting (A)	Needed both halves	Machete	8	X
Weaving (A)	Better rain protection	Hand labor	8	2
Installing (A)	First row shingles; base-layer	Hammer; nails	7	1
Panama hat plant- *Carludovica palmata*-**(P)**				
Cutting (P)	Harvested for shingling	Machete	~8000	36
Halving (P)	Alternate right & left shingling	Hand labor	~16000	21
Bundling halves (P)	To carry to building site	4 branches; palm stems	~16000	18
Separating (P)	Organization of site	Hand Labor	~16000	21
Tying up (P)	To raise to ceiling level	Vines, string	~16000	56
Installing (P)	Shingling	Hand labor	~15950	56

Table 3: Construction task list: A comprehensive table broken into specific task for the construction of the school. Species listed include: Hardwood- *Calycophylum spruceanum*-(W); Palm wood- *Iriartea deltoidea*- (I); Bamboo- *Guadua angustifolia*-(B); Palm- *Attalea butyracea*- (A); Panama hat plant- *Carludovica palmata*-(P). In total 267 hours were spent over the course of 26 days to complete the list of tasks. See Appendix A for further details on construction language. *Delivered material

The final result of the construction process: a newly reconstructed school to spread conservation awareness on Sumak Allpa. The extra materials—such as the 50 unused Panama hat plant leaves—were salvaged for the next reconstruction of another house on the island, which begun shortly after the completion of the school (Table 3).

DISCUSSION

Sumak Allpa analysis

With the combination of the density studies and having participated in the daily tasks of reconstruction of the school, the use of natural materials is astounding. Looking at the results from the Panama hat plant density test—specifically Figure 9—the relative number of leaves we left within the scope of each subplot is quite wonderful. The growth rate of *C. palmata* was studied to be 4-5 plastochrons—the time it takes to sprout a new leaf—before fully mature (Wilder, 1976). A common sign of maturity noted in the field was a deep green colored stem; those that were young leaves had white to pasty green stems. During the first day of harvesting the leaves, Román reminded me to only cut the darkest stems, for they were going to be the most water resistant and durable over time (Román, personal communication, April 13, 2019) In another study, community residents were particularly conscious about not taking the "babies" and tended to harvest only mature adult trees as well (Fadiman,2019). Depending on the region, adult leaves can grow more rapidly, varying with each stage of the leaf (Wilder, 1976). In a conversation with Héctor Vargas, he explained that on Sumak Allpa one Panama hat plant reaches full maturity in five years)—from seed to maturity (H. Vargas, personal communication, April 25, 2019).

To date, *C. palmata* is currently considered a state of least concern (Brummitt, 2013). Therefore although the population is restricted on Sumak Allpa, sourcing from other parts of the mainland put no immediate threat on the species population. This can be further analyzed by looking at the densities within the island: of the 21,255 leaves accounted for only 7,412 were harvested (34.87%) for constructional purposes. Two-thirds of the area studied were left unharmed. The only threat that could be posed on the island's population could be rebuilding another facility using the same palms. Luckily, the next project will be using *Attalea butyracea* for its roofing material, of which were imported from another forest 15km up the Napo river.

It has also been said that like the construction history of the school, these palms have proved their durability over the last two decades on Sumak Allpa. In a study comparing the durability and material makeup of eight different species within the Cyclanthaceae family, it was found that *C. palmata* had the highest density of fibers inside its stem. This not only is beneficial for the lifespan of the palm after harvest, but it proves to be the strongest for harsh inundated conditions (Medina, 2017). Especially for Sumak Allpa, a várzea ecosystem, *C. palmata* kept the inside of the school dry for 10 years before needing a replacement.

The bamboo species that made up the rafters of the roof, *G. angustifolia (*Guadua*)*, was the posture of the infrastructure. Supporting more than 16000 individual Panama hat plant leaves—all of which retaining 10 years of moisture and hundreds of insect habitats—the highly flexible yet stable properties of the bamboo rafters kept them from collapsing over the span of 10 years. *G. angustifolia* is one of the most common bamboos used for building among the Amazon. Endemic to the region, it grows at a rapid 21cm per day and a single shoot can reach up to 25m in 6 months. The maximum diameter can grow to 22cm, holding substantially loads without causing too much stress on the material (Archila Santos, 2012). And as it has grown across the island of Sumak Allpa, it has become an abundant, readily available resource for island construction.

Little was known about the Guadua population on the island before this study. Based on the results from the transect, the population stretches far into the forest more than was needed. The increasing slope of Figure 12 demonstrates the increasing density of each proceeding quadrat as well; the majority of the bamboo is collected where more convenient to the harvesters. Several rotting bamboo bases and scraps were found along Jatun, which although were not recorded during the study, it suggests that the ratio of harvested to remaining shoots in quadrat 1 could become threatening during the next reconstruction project. At the 60m mark along the transect, none of the individuals recorded had been affected by the harvesting process for the construction of the school. It was noted in Table 3 that 46 bamboo shoots were needed for the completion of the roof of the school. Based on Table 2, only 27 were recorded. The population stretches well over 10 hectares, and if within two 25m² quadrats more than half the shoots were harvested for the construction of one of six naturally-built facilities on Sumak Allpa—remembering that roofs are replaced about once a decade—then that is ~0.1% of the needed for this project. As stated earlier, in a six-month time period, Guadua can grow up to 25m tall. After the turn of the next decade, the population of Guadua could multiply exponentially throughout the island—may this act as a baseline study to further understand the growth rate of this species. Ultimately, the population was almost untouched, and if the rate of construction continues to remain decennially, the Guadua population will continue to prosper.

Construction & technique analysis

The minor objective of the study was to understand how one approaches building a house completely out of naturally sourced, local materials. With a background in architectural engineering, I wanted to understand the building process while taking note of the environmental impacts (positive or negative) along the way.

Most of the observations were qualitative, but several quantitative findings can still be extracted from the results. Five species in total were used to construct the school—no plastics, no glass, no electrical hookups. In comparison to the standard construction of a US home from a study of the carbon footprint of constructing a new home in the state of California states, "the carbon emissions from a new home built to 2006's code was 8.2 metric tons of CO2e per house per year," (ConSol, 2008). An equal portion is saved in cost too. In a conversation with Román, he said that a regular palm thatched house can cost up to $15,000. Building on an island limited us from purchasing goods, of which the cost of construction materials was freely sourced from the surrounding jungle.Consequently, time was the largest factor that was lost; taking 21 days to fully reconstruct a 31.5m² roof as opposed to having powerful machinery to do the work in a matter of days.

Furthermore, during the harvesting process of the Guadua shoots, those that maintained a relative thickness (approx. 15cm) for the required rafter length were chosen. As the shoot grows the thinnest part continuously spouts from the top; therefore although the younger half of the plant was not used in the project, it was placed back in its relative environment to be decomposed and recycled. Noches were cut with machetes to then hook onto the pambil based ridge beam (Figure 14).

Figure 14: Rafter noches Hooks carved into Guadua shoot that will hang on the ridge beam

The Panama hat plant installation took up the majority of our time. When constructing the roof, we alternated between right and left sided leaves, tying off bushels of 15-20 to then hand fold each leaf onto the Guadua under purlin (Figure 15). The process took well over 100 hours of labor; as often rural communities that are not well regulated can easily be illegally exploited for their labor, getting paid under the national minimum wage of $7.25 ("Ecuador Minimum Wage Rate 2019", 2019). The pain of the labor could be seen and physically felt after each day.

Figure 15: Panama hat plant leaf installation 16000 hand folded onto bamboo under purlins

As every piece of lumber, bamboo, palm, and leaf was brought to the construction site by sheer human strength, the relationship to the surrounding community strengthened tenfold. I witnessed the flora species serve a greater benefit than to its ecosystem; *we* became part of the ecosystem in the process. It kept us from over-harvesting and gave greater purpose to every piece of material harvested from the island.

Study Considerations & Future Work

With any comprehensive undergraduate study, there were several limitations, unexpected failures, and improvements that could be enforced in a future study. Although we took from several locations of the forest, there were other fauna species that were displaced or harmed throughout my time there. There were times when the timeline of construction took precedence over any factors that limited it; countless number of miniature habitats—spiders, frogs, snakes—were compromised. In times of harvesting a hardwood tree, it was astounding the number of understory species it fell upon. In future studies, it would be interesting to track the damage of such behavior on the greater ecosystem, something that was out of the scope of this study. The burning of the remains of the old school's materials left physical damage to the surrounding forest, something that raises both environmental and ethical questions.

The density plot and transect were relatively arbitrary; the densities did not have a baseline study which made it hard to compare across a healthy population of the island. It would have been helpful and more trackable if I were to have picked subplots in the Sumak Allpa Long Term Study Plot (SALTSP) that has pre-established boundaries. It seemed irrelevant at the time, for that was not where we were harvesting our building materials. Studies that measure MSDR such as the one conducted in Japan that helped further understand the self-thinning capacity of *Phyllostachys pubescens* could be beneficial for the future density studies of Guadua on the island (Inoue, 2018).

I also encountered problems with camera GPS tracking—reasons for approximate locations on the Sumak Allpa map. Physical strength also was quite hindering, but not first expected at a limitation. Carrying materials to the job sit was the most physically demanding, keeping me from participating in most of the heavy lifting. My body had yet to adjust to the intense conditions of the Amazon—precaution advised. Miscommunication also happened daily, for Luís and Román's native language was Kichua.

Despite some of these issues, the largest I had was balancing better three different studies; with the varying Amazonian thunderstorms, it was difficult to gauge when to conduct the density studies and when I would be working. Since I was a volunteer, I did not feel pressured to work, for they knew I was a student, but if I were to relive the same situation again, I would only focus on one of the density studies to give a sharper focus to my overall project.

CONCLUSION

This study was an accumulation of relative densities of naturally sourced construction materials and tracking the reconstruction process for a school on Sumak Allpa. The school has been refreshed with 4 pambil ceiling joists, 40 new Guadua rafters, and 16000 Panama hat plant leaves shingles. With over 250 hours of work split between three workers, the core purposes of monkey rehabilitation, active conservation efforts, and promoting the communities and cultures of the Orellana Province have once again been a shelter to teach. It was found that the reconstruction of this 7m x 4.5m site had little to no impact on the overall populations of the island, due to both the abundance of material and conscious effort to preserve it. By harvesting only what was necessary and having an awareness of the health of the surrounding ecosystem, the reconstruction of one of the six standing structures on Sumak Allpa proved to be environmentally stable. Leaving with a better understanding of the effort it takes to build on an isolated island of the Amazon with nothing but a machete, I have grown an appreciation for the process of natural construction and shelter as a whole. The emphasis on small communities are also relevant, for on an island inhabited by 4-8 people at a time, the demand for the extraction of natural resources remains balanced on a 115-hectare plot of land. Finally, taking into consideration the relative closeness to nature, it can be concluded that longer exposure to a surrounding environment increases one's awareness of the ways in which we can save, protect, and properly harvest it for our benefit.

BIBLIOGRAPHY

Amazon Rainforest. (2019). In *Encyclopædia Britannica*. Retrieved from https://academic-eb-com.colorado.idm.oclc.org/levels/collegiate/article/Amazon-Rainforest/6028

Amazon River. (2019). In *Encyclopædia Britannica*. Retrieved from https://academic-eb-com.colorado.idm.oclc.org/levels/collegiate/article/Amazon-River/109565

Archila Santos, H. F., Ansell, M. P., & Walker, P. (2012). Low carbon construction using Guadua Bamboo in Colombia. *Key Engineering Materials*, *517*, 127-134. https://doi.org/10.4028/www.scientific.net/KEM.517.127

Arcuri, Paulina, "A Study of Threatened Juvenile Woolly Monkeys: An Assessment of Natural Rehabilitation of Juvenile Wooly Monkeys (Lagothrix lagotricha poeppigii) on Sumak Allpa Island, Ecuador" (2017). *Undergraduate Honors Theses*. 1519. https://scholar.colorado.edu/honr_theses/1519

Bass MS, Finer M, Jenkins CN, Kreft H, Cisneros-Heredia DF, et al. (2010) Global Conservation Significance of Ecuador's Yasunı´ National Park. PLoS ONE 5(1): e8767. doi:10.1371/journal.pone.0008767

Brummitt, N. (2013). *Carludovica palmata*. *The IUCN Red List of Threatened Species* 2013: e.T44392681A44401274. http://dx.doi.org/10.2305/IUCN.UK.2013-2.RLTS.T44392681A44401274.en.

Cochrane, M. A., & Laurance, W. F. (2008). Synergisms among fire, land use, and climate change in the Amazon. Ambio, 37, 522-527. doi:10.1579/0044-7447-37.7.522

ConSol (2008) *Carbon Footprint of Single-Family Residential New Construction*. Retrieved from https://www.consol.ws/pdf/Carbon-Footprint-of%20Single-Family-Residential-New-Construction.pdf

Ecuador Approves Yasuni Park Oil Drilling In Amazon Rainforest. (2013). *YaleGlobal Online*. Retrieved from http://link.galegroup.com.colorado.idm.oclc.org/apps/doc/A342745965/AONE?u=coloboulder&sid=AONE&xid=263f9931

Ecuador Minimum Wage Rate 2019. (2019). Retrieved from https://www.minimum-wage.org/international/ecuador

Escamilla E., & Habert, G. (2014) *Environmental impacts of bamboo-based construction materials representing global production diversity.* Retrieved from http://elservier.com/locate/jclepro

Fadiman, M. (2019). Can the Use of a Specific Species Influence Habitat Conservation? Case Study of the Ethnobotany of the Palm Iriartea Deltoidea and Conservation in Northwestern Ecuador. *Journal of Latin American Geography* 18(1), 115-140. University of Texas Press. Retrieved May 10, 2019, from Project MUSE database.

Flores, C. F., & Ashton, P. (2000). *Harvesting Impact and Economic Value of Geonoma Deversa, Arecaceae, an Understory Palm Used for Roof Thatching in the Peruvian Amazon*. Economic Botany 54: 267-277.

Fraser, B. (2014). Carving up the Amazon: a rash of road construction is causing widespread change in the world's largest tropical forest--with potentially global consequences. *Nature*, *509*(7501), 418+. Retrieved from http://link.galegroup.com.colorado.idm.oclc.org/apps/doc/A369462013/SCIC?u=coloboulder&sid=SCIC&xid=bfd36034

Freimuth, Sara, "Herpetofauna of Sumak Allpa: A Baseline Assessment of an Unstudied Island Herpetofaunal Community" (2018). *Independent Study Project (ISP) Collection*. 2784. https://digitalcollections.sit.edu/isp_collection/2784

Gallegos, Rachel, "The development of a reproductive population of chorongos: Intergroup interactions, dispersal, and sexual behavior of Lagothrix lagotricha poeppigii in natural rehabilitation on the island of Sumak Allpa, Ecuador" (2016). *Independent Study Project (ISP) Collection*. 2474. https://digitalcollections.sit.edu/isp_collection/2474

Inoue, A., Sato M., & Shima H (2018). Maximum size-density relationship in bamboo forests: Case study of Phyllostachys pubescens forests in Japan. *Forest Ecology and Management* (425), 138-144. https://doi.org/10.1016/j.foreco.2018.05.044.

Medina, M.C., Hoyos-Goméz, S.E., Demarco, D., & Tuberquia, D.J. (2017). Peculiar anatomical traits, high durability, and potential ornamental use of Cyclanthaceae as fresh foliage. *Anais da Academia Brasileira de Ciencias, 89 3 Suppl*, 2399-2410 .

Sajo, M., Lombardi, J., Forzza, R., Rudall, P., & Editor: Alan W. Meerow. (2014). Comparative Anatomy of Reproductive Structures in Cyclanthaceae (Pandanales). *International Journal of Plant Sciences*, *175*(7), 814-827. doi:10.1086/676817

Van, D. P. (2013). *The impact of the iirsa road infrastructure programme on amazonia*. Retrieved from https://ebookcentral.proquest.com

Vargas, H. (2012). *Sumak Allpa: Main Project*. Retrieved from http://sumakallpa.org/index.php/main-project

Wilder, G. (1976). Structure and Development of Leaves in Carludovica palmata (Cyclanthaceae) with Reference to Other Cyclanthaceae and Palmae. *American Journal of Botany*, *63*(9), 1237-1256. Retrieved from http://www.jstor.org/stable/2441740

APPENDIX

All appendices and further content can be found by following this Google Drive link (save the trees):

https://drive.google.com/open?id=1OQ3HF47Ll_yz1SaFxdhWKzRR5JztXLgM